Perception & Psychophysics
1983, 33 (1), 11-19

Color segregation and selective attention in a nonsearch task

LISBETH HARMS and CLAUS BUNDESEN
Copenhagen University, Copenhagen, Denmark

Relations between selective attention and perceptual segregation by color were investigated in binary-choice reaction time experiments based on the nonsearch paradigm of Eriksen and Eriksen (1974). In focused attention conditions (Experiment 1), noise letters flanking a central target letter caused less interference when they differed from the target in color, although color carried no information as to whether or not a letter was the target. When blocking of trials favored a strategy of dividing attention between target and noise letters (Experiment 2), no benefit accrued from difference between target color and noise color. The results supported an attentional interpretation of the effect of color demonstrated in Experiment 1, implying that perceptual segregation by color improved the efficiency of focusing attention on the target.

Recent studies have demonstrated remarkable deficits in subjects' abilities to control their visual information processing by focusing attention on stimuli in a prespecified spatial location (cf. Egeth, 1977; C. W. Eriksen & Schultz, 1979; Shiffrin & Schneider, 1977). A binary-choice reaction time experiment by B. A. Eriksen and C. W. Eriksen (1974) provides a good example. Subjects were presented with displays in which a central target letter appeared alone or flanked by a number of noise letters. The target was always presented directly above the fixation point, and the required response was uncorrelated with the number and type (response compatible, incompatible, or neutral) of noise letters. For all types of noise, reaction time increased as between-letter spacing decreased, but interference was stronger with response-incompatible than with neutral noise and stronger with neutral than with response-compatible noise. Eriksen and Eriksen concluded that the subject "cannot prevent processing of noise letters occurring within about 1 deg of the target due to the nature of processing channel capacity and must inhibit his response until he is able to discriminate exactly which letter is in the target position" (p. 143). (See, also, Colegate, Hoffman, & C. W. Eriksen, 1973; C. W. Eriksen, Hamlin, & Daye, 1973; C. W. Eriksen & Hoffman, 1972, 1973; Taylor, 1977.)

The focused-attention deficits shown in experiments like that of B. A. Eriksen and C. W. Eriksen (1974) are consistent with the hypothesis that the field of visual attention cannot be narrowed to spanning less than about 1 deg of visual angle around a given target. A different interpretation, however, may be based on the notion that spatial selectivity is limited by the operation of a "preattentive" (Neisser, 1967) stage of "unit formation" (Kahneman, 1973; Kahneman & Henik, 1977, 1981) such that attention can be selectively allocated only to parts of the visual field that have been segregated as separate units at this stage (cf. Banks & Prinzmetal, 1976; Prinzmetal & Banks, 1977). The notion suggests that the weaker the perceptual segregation between two elements in the visual field, the less efficiently attention can be focused on one of these elements to the exclusion of the other. Unit formation should be governed by the Gestalt principles of perceptual grouping and organization (Wertheimer, 1923). By the principles of proximity and similarity, target and noise elements in the experiments considered above should tend to be grouped together, and the closer the spacing, the weaker should be the perceptual segregation of the target from the noise elements. Rather than reflecting an irreducible minimum spatial extent of the field of attention, then, the focused-attention deficits found in these experiments may reflect the strength (or weakness) of the perceptual segregation of target from noise.

The preceding considerations suggest that spatial selectivity might be enhanced by strengthening the perceptual segregation between target and noise elements even if neither the spatial arrangement nor the task-related informational value of the stimulus elements were changed. The present study was designed to test this conjecture by varying the similarity in color between target and noise elements presented in the field of central foveal vision.

This research formed the basis of a thesis (specialeopgave) by the first author, supervised by the second author. The present report represents the equal and shared contributions of both authors. Jørgen Rathje provided technical support. Requests for reprints should be directed to Claus Bundesen, Psychological Laboratory, Copenhagen University, Njalsgade 90, DK-2300 Copenhagen S., Denmark.

Separating target from noise by color has been highly effective in visual search (Cahill & Carter, 1976; Carter, 1982; Farmer & Taylor, 1980; Green & Anderson, 1956; Smith, 1962; Treisman & Gelade, 1980; Williams, 1966), partial report (Broadbent, 1970; Clark, 1969; Fryklund, 1975; Kahneman & Henik, 1977, 1981; Keren, 1976; von Wright, 1968, 1970, 1972), and related paradigms (e.g., Francolini & Egeth, 1979, 1980). In the current experiments, based on the nonsearch paradigm of B. A. Eriksen and C. W. Eriksen (1974), we explored the effects of varying similarity in color between target and noise *without* coding the target by color.

EXPERIMENT 1

In each stimulus display, a central target element appeared alone or flanked on each side by a noise element. A three-element display subtended about 1 deg of visual angle. Each of the noise elements could be colored the same as, or differently from, the target. The subject was to respond to the identity of the target, and neither identity of noise elements nor coloring of noise and targets carried any information about target identity. Moreover, to prevent the subject from using color as a secondary criterion in selecting the target (spatial position being the primary criterion), the color of an element carried no information as to whether or not that element was the target (cf. Humphreys, 1981). However, having a noise element appear in a color different from that of the target should strengthen the perceptual segregation between that noise element and the target, and we hypothesized that this would increase the efficiency of focusing attention on the target to the exclusion of the noise element. Accordingly, we predicted some improvement in performance when one, as opposed to none, of the noise elements in a display was different in color from the target and further improvement when both noise elements were segregated from the target in this way.

Method

Subjects. Eight right-handed subjects with normal or corrected-to-normal vision participated; these included the two authors and six students or members of the staff at Copenhagen University. Four of the subjects had had previous experience with reaction time tasks.

Stimuli. The stimulus material consisted of 184 slides on which a centered target letter appeared either alone or flanked on each side by a noise letter. The letters were red (with an approximate Munsell notation of 7.5R 5/12) or black, and the background was white. The target was a T or an F, and each noise letter was a T, an F, or an H. Combining two colors with two identities gave four different displays in which the target appeared alone, and combining 2×2×2 combinations of colors with 3×2×3 combinations of identities gave 144 different displays in which the target was flanked on the left and on the right by noise letters. Each of the four one-element displays was represented by four identical slides. Among the 144 three-element displays, 24 displays had left and right noise elements that were the same with respect to both color and identity. Each of these 24 three-element displays was represented by two identical slides, and each of the remaining three-element displays was represented by a single slide.

Noise elements were described in terms of their response compatibility with and color segregation from the target. If the target was a T, noise elements T, H, and F were described as response compatible, neutral, and incompatible with the target, respectively, but if the target was an F, F was response compatible, H neutral, and T incompatible. A noise element was color segregated from the target if, and only if, it differed from the target in color. By classifying in terms of both response compatibility and color segregation, we got six types of noise elements. Classification of the possible displays on the basis of the number of noise elements of each of these six types produced 6 equivalence classes of displays with two noise elements of the same type, $\binom{6}{2} = 15$ classes of displays with two noise elements of different types, and one class containing the one-element displays. Note that, for any of the four combinations of target color and identity, each of the 21 equivalence classes of three-element displays was represented by two slides and the class of one-element displays by four slides.

The 184 slides were arranged in eight blocks of 23 slides such that each of the 21 equivalence classes of three-element displays was represented once per block whereas the class of one-element displays was represented twice per block. Except for this constraint, the stimulus sequence was random. A new randomization was made for each session.

Procedure. The subject was seated 3.5 m in front of a screen on which rear-projections of the slides spanned approximately 1.31 deg horizontally and .85 deg vertically. Each stimulus letter spanned about .48 deg vertically and .33 deg horizontally. The target appeared above a constant fixation mark positioned .33 deg below the center of the display. The center-to-center distance between target and noise letters was approximately .38 deg. Viewing was binocular. During projection of a slide, the pupils of the subject received an illuminance of about .5 lx from the stimulus field and 15 lx from the surrounding field.

When the subject pressed a starting key, a slide was projected with a latency of 2,000 msec. The subject was instructed to decide "as quickly as possible" whether the central target letter was a T or an F. The decision was indicated by pressing a left- or a right-hand button, and reaction time was measured in milliseconds from stimulus onset. Stimulus exposure terminated with a latency of 50 msec when one of the response buttons was pressed, and the next slide was projected after a fixed intertrial interval of 2,000 msec unless the subject opted for a pause by pressing a halt key. The experiment was run by a laboratory computer with a crystal clock.

The subjects served individually in one practice and four experimental sessions. The practice session comprised a run through the set of 184 slides. In each experimental session, the 184 slides were presented twice. Throughout the experiment, four of the subjects were required to respond to target T with the left hand and to target F with the right hand; the other four subjects were run with the reverse response assignment.

Results

Reactions with a latency greater than 2,000 msec were not analyzed; this eliminated 4 of 11,776 trials. All analyses of reaction times were based on correct reactions. Individual error rates ranged between .014 and .063.

Both reaction times and error rates showed clear main effects of response compatibility and color segregation. For no-noise (i.e., one-element) displays, the mean reaction time for the eight subjects was 460 msec and the error rate, .023. When the target was flanked by noise elements, mean reaction time increased. Across conditions of color segregation, the increment was 3 msec for purely compatible noise, 16 msec for mixed compatible-neutral, 22 msec for purely neutral, 29 msec for compatible-incompatible, 39 msec for neutral-incompatible, and 51 msec for purely incompatible noise. Measured by increase in rate of errors as compared with the no-noise condition, the effect of noise elements was −.002 for purely compatible noise, .003 for mixed compatible-neutral, .012 for purely neutral, .017 for compatible-incompatible, .019 for neutral-incompatible, and .045 for purely incompatible noise.

Across conditions of response compatibility, mean reaction time and error rate varied systematically as functions of the number of noise elements being segregated from the target by color. Figure 1 summarizes the group results for red vs. black target letters (across sessions) and for Sessions 1 and 2 vs. Sessions 3 and 4 (across colors of targets). Regardless of the level of color segregation, reactions were slower and less accurate for displays with noise elements than for no-noise displays. But for each color of target, and for early as well as late sessions, reactions to displays with noise elements were faster and more accurate the greater the number of noise elements that were segregated from the target by color. As illustrated in Figure 2, the individual data were similar in pattern for seven of the eight subjects. The deviant subject (represented by the lowest curve in Figure 2) showed little effect of noise and no measurable effect of color segregation. The data for the deviant subject are not included in the more detailed analyses that follow.

Reaction times for three-element displays were subjected to a three-factor repeated-measures ANOVA with nine levels of the response compatibility factor (the nine combinations of compatible, neutral, and incompatible left and right noise letters), four levels of the color segregation factor (segregation of none, left, right, or both noise letters, respectively), and two levels of target color (red vs. black). Under the conservative Greenhouse-Geisser test pro-

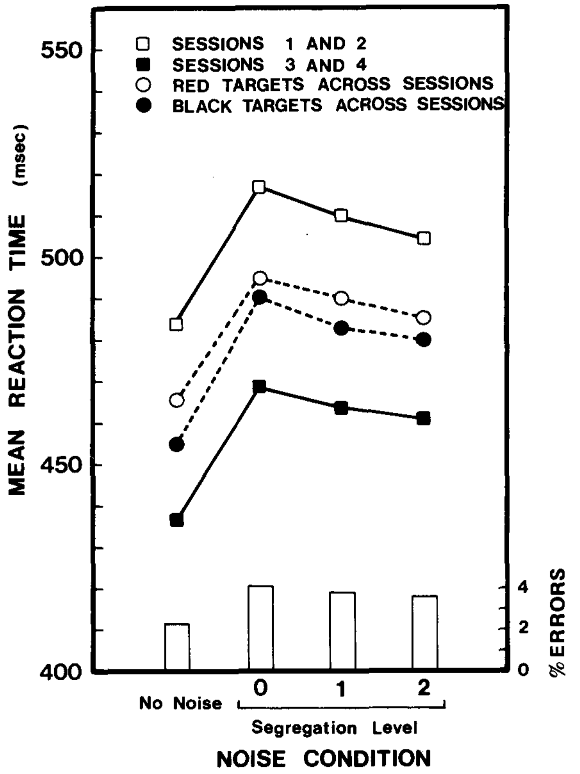

Figure 1. Mean reaction times for red vs. black target letters (across sessions) and for Sessions 1 and 2 vs. Sessions 3 and 4 (across colors of targets) as functions of noise conditions in Experiment 1. (Noise was either absent or present. At segregation level i (i = 0, 1, or 2), i out of two noise letters were segregated from the target by color. Data are averaged over eight subjects. The mean rate of errors is shown in the bottom panel.)

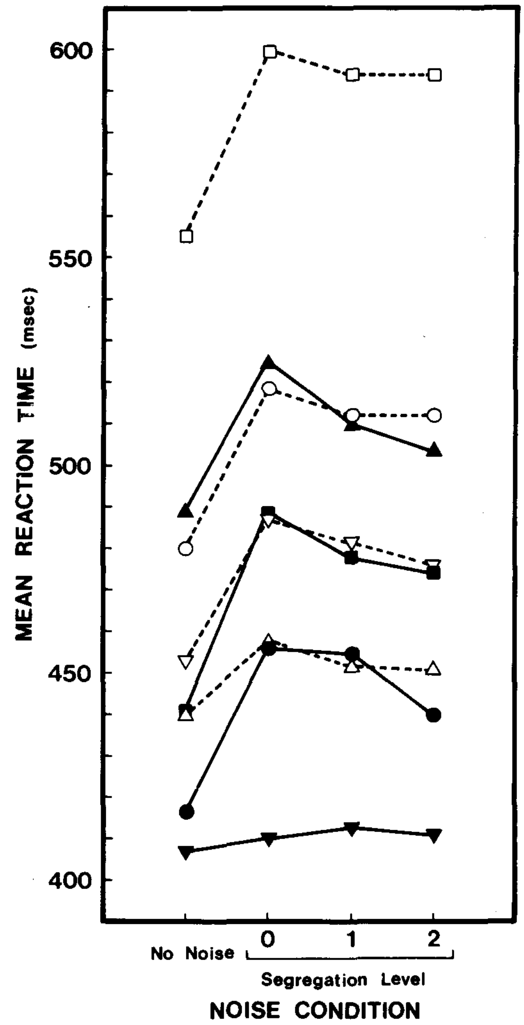

Figure 2. Mean reaction times for each of eight subjects as functions of noise condition in Experiment 1. (Noise was either absent or present. At segregation level i (i = 0, 1, or 2), i out of two noise letters were segregated from the target by color.)

cedure (cf. Winer, 1971, p. 523), the effects of response compatibility [$F(1,6) = 17.4$, $p < .01$] and color segregation [$F(1,6) = 17.3$, $p < .01$] were significant and the effect of target color (see Figure 1) was marginally significant [$F(1,6) = 4.84$, $.05 < p < .10$]. The interaction between response compatibility and color segregation was not significant [$F(1,6) = 1.41$, $p > .10$], nor were any of the other interactions (in each case, $p > .10$). (Including the deviant subject in the ANOVA would not have affected the conclusions, except for the fact that the main effect of target color would have reached significance at the .05 level.)

Table 1 shows both mean reaction time and error rate as functions of response compatibility with and color segregation from target for left and right noise letters, averaged over target colors. Though interaction between response compatibility and color segregation was negligible in latency, it was noticeable in accuracy. Thus, over the nine combinations of compatible, neutral, and incompatible left and right noise letters, the product-moment correlation between mean reaction time (across conditions of color segregation) and gain in accuracy as measured by decrease in error rate by two-sided color segregation was .74 ($p < .05$).[1]

For those five compatibility conditions in which one or more incompatible elements appeared, the decrease in mean reaction time with segregation of both noise elements averaged 14 msec [$t(6) = 3.52$, $p < .01$], and the rate of errors concomitantly decreased from .057 to .040 [$\chi^2(14) = 24.7$, $p < .05$].[2] For the four combinations of compatible and neutral noise elements, segregation of both elements effected a decrease in mean reaction time, which averaged 13 msec [$t(6) = 4.03$, $p < .01$], while the rate of errors increased from .024 to .030. The rate of .024 was lower than the error rate for no-noise displays (.027), although the difference was not significant.

Effects of color segregating just one of two noise elements from the target showed a similar pattern. If the segregated noise element was response incompatible with the target, the segregation effected a clear improvement in performance: Mean reaction time decreased some 9 msec [$t(6) = 3.51$, $p < .01$], and the rate of errors decreased from .057 to .048. If the segregated noise element was compatible or neutral, performance improved in terms of latency, but the rate of errors showed some increase. For compatible noise elements, mean reaction time decreased about 13 msec [$t(6) = 4.73$, $p < .01$], and the error rate increased from .029 to .031. For neutral noise elements, mean reaction time decreased about 5 msec [$t(6) = 1.52$, n.s.], while the error rate increased from .030 to .040.

Laterality. The effect of response compatibility was greater for elements in the left visual field than for elements in the right visual field. Thus, for both mixed compatible-neutral, mixed compatible-incompatible, and mixed neutral-incompatible displays, reactions were slower and less accurate when the more strongly interfering noise element was positioned in the left field. Across conditions of color segregation, the reaction time difference averaged about 10 msec over the three types of mixed displays [$t(6) = 2.92$, $p < .05$], and the difference in error rate averaged .007.

The effect of color segregating just one of two noise elements from the target was also greater when the segregated element was that in the left visual field. Across compatibility types, segregation of the left noise element effected a decrease in mean reaction time of 11 msec [$t(6) = 10.02$, $p < .001$] and a decrease in error rate from .040 to .037; segregation of the right noise element effected a decrease in mean reaction time of 6 msec [$t(6) = 2.70$, $p < .05$] accompanied by an increase in error rate from .040 to .043. The interaction in mean reaction time between color

Table 1
Mean Reaction Time (in Milliseconds) and Error Rate (ER) as Functions of Response Compatibility With and Color Segregation From Target for Left and Right Noise Letters in Experiment 1

		Segregation of							
Compatibility of		None		Left		Right		Both	
Left	Right	RT	ER	RT	ER	RT	ER	RT	ER
Blank	Blank	468	.027						
Compatible	Compatible	480	.022	463	.009	470	.027	472	.025
Compatible	Neutral	492	.022	482	.031	495	.018	476	.031
Neutral	Compatible	499	.009	483	.036	485	.040	485	.027
Neutral	Neutral	498	.033	483	.045	506	.036	485	.036
Compatible	Incompatible	510	.045	491	.022	495	.031	492	.031
Incompatible	Compatible	511	.054	502	.036	506	.054	505	.045
Neutral	Incompatible	517	.018	508	.022	493	.018	490	.036
Incompatible	Neutral	527	.063	517	.049	522	.085	514	.031
Incompatible	Incompatible	523	.080	524	.080	528	.076	521	.049

Note–Data are group results for seven subjects.

segregation and visual field was significant [$t(6) = 3.61, p < .05$].

Discussion

The main effects of response compatibility of noise elements accord with the results provided by B. A. Eriksen and C. W. Eriksen (1974), at least for seven of our eight subjects. A simple explanation of the effects is outlined below (see C. W. Eriksen & Schultz, 1979, for another approach).

Following the onset of a stimulus, sensory information was accumulated that a central T or a central F was present. Let e(T) and e(F) be the accumulated evidence (measured on an interval scale) in favor of a central T and a central F, respectively. If and when the numerical difference between e(T) and e(F) exceeded a threshold value ε, then the response supported most strongly by the evidence was evoked. However, sensory information was noisy with respect to spatial position as well as identity. If the target was flanked by a T, the evidence in favor of a central T was inflated. Similarly, a noise F contributed to e(F) rather than e(T), but noise H affected e(T) and e(F) more equally.

The suggested account explains why, compared with reactions in the face of neutral noise, reactions with compatible noise were faster and more accurate, whereas reactions with incompatible noise were slower and less accurate. The decrease in speed and increase in accuracy obtained with compatible noise as compared with the no-noise condition may be explained by a further assumption: sensory information that the target was accompanied by noise elements effectively added to the value of ε, making the subject more cautious with three-element than with one-element displays.

The main effects of color segregating noise elements from the target conformed to our prediction. We supposed that the stronger the perceptual segregation between two elements in the visual field, the more efficiently could attention be focused on one of these elements to the exclusion of the other. Color segregating a noise element from the target should strengthen the perceptual segregation between that noise element and the target, whence the efficiency of focusing the target to the exclusion of the noise element should increase. This explains why overall performance in speed and accuracy improved when one of the noise elements in a display was color segregated from the target and why further improvement was obtained by segregation of both noise elements from the target. The effects were highly reliable; they were seen for each color of target, for early as well as late sessions, and for each of the seven subjects who were noticeably affected by the presence of noise.

Absolute color was less important than color relations. In a comparable experiment, C. W. Eriksen and Schultz (1979, Experiment 1) found strong effects of black vs. low-contrast yellow targets on a white background. Whether a target was presented alone or flanked by black noise elements, performance was better when the target was black than when it was yellow. The difference was assumed to reflect differences in the summation time required to resolve critical detail in the visual system. In the present experiment, however, both red and black letters were high in contrast to the background.

Response compatibility and color segregation interacted significantly in accuracy, but not in latency. On the whole, the pattern appears to be consistent with a hypothesis that the more strongly a noise element interfered, the greater was the benefit from having that noise element segregated from the target by color. Consider the effects of color segregating both noise elements in a display from the target. For displays with one or more incompatible noise elements, performance improved in both speed and accuracy. For displays with compatible and neutral noise elements only, the benefit was less, namely, a comparable gain in speed with some loss in accuracy. Similar effects were observed with color segregation of just one of two noise elements. If the segregated element was incompatible with the target, performance improved in both speed and accuracy; if the element was compatible or neutral, performance improved in speed but worsened slightly in accuracy.

To understand the results for compatible and neutral noise in greater detail, we speculate that a speed-accuracy tradeoff occurred as follows. As previously suggested, sensory information that the target was accompanied by noise elements effectively added to the threshold value ε, making the subject more cautious with three-element displays than with one-element displays. However, sensory information that the target was flanked by color-segregated noise added less to the value of ε than did information about noise elements in the same color as the target, making the subject somewhat less cautious with color-segregated than with color-nonsegregated three-element displays. With sufficiently weak distractors (compatible or neutral noise), then, color segregation produced faster but less accurate performance.

Effects of laterality were orderly. For all types of mixed-noise displays, performance degraded more when the more strongly interfering type of noise element was positioned in the left rather than in the right visual field. Apparently, the perceptual impact of a noise element was stronger when the element was presented to the left visual field/right hemisphere than when presented to the right visual field/left hemisphere (cf. Hellige, 1980; Hellige & Webster, 1979; Polich, 1978). In agreement with the hypothesis that the more strongly a noise element interfered, the greater was the benefit by color segregation of that noise element from the target, improvement in performance was greater by color segregation of a noise element in the left than by one in the right visual field.

Alternative interpretations. In the suggested interpretation, performance improved with color segregation because color segregation made attentional focusing more efficient. Two alternative, nonattentional interpretations will be considered. First, effects of color segregation in performance might reflect variations in the time taken to segment a three-element display into separate units at the level of individual characters, and these perceptual variations might be independent of attentional conditions. The segmentation operation could be thought of as a mandatory step in preprocessing for character recognition (cf., e.g., Ullmann, 1973, p. 37)—resistant to attentional control, but sensitive to differences in color between characters. If color segregation of both noise elements from the target automatically speeded up perceptual segmentation of the display into separate units at the level of individual characters, perception and performance should improve by two-sided color segregation.

Extending this nonattentional interpretation to the effect of one-sided color segregation is more difficult. The interpretation implies that when a noise element is color segregated from the target, perceptual processing of the noise element is speeded and the impact of the noise element should thereby (cf. C. W. Eriksen & Schultz, 1979) be enhanced. However, to accommodate the fact that performance was improved rather than degraded by one-sided color segregation, ad hoc assumptions might be made that (1) segregation of the target from the color-nonsegregated noise element was facilitated, and (2) this facilitation overrode the detrimental effects of speeded processing of the color-segregated noise element.

Second, effects of color segregation might be explained by *color specificity of inhibitory lateral interactions*, such as lateral masking (cf. Wolford, 1975; Wolford & Hollingsworth, 1974), feature-specific inhibition (Bjork & Murray, 1977; Santee & Egeth, 1980), or contour interaction (Flom, Weymouth, & Kahneman, 1963). Suppose, for example, that lateral masking is stronger between same-colored than between different-colored characters. Color segregating a noise element from the target should then weaken lateral masking between that element and the target. This effect might generate the gain in performance obtained when one of the noise elements in a display is color segregated from the target and the further gain resulting from segregation of both noise elements from the target.[3]

Apparently, the pattern of results explained by our attentional interpretation might also be explained by such nonattentional perceptual conditions as color-based variations in segmentation time or color-specific inhibitory lateral interactions. Moreover, the attentional and nonattentional hypotheses are not mutually exclusive, and a combination of variation in efficiency of attentional focusing and nonattentional variations in efficiency of perceptual processing might underlie the data. Experiment 2 was designed to evaluate the possible contribution of nonattentional perceptual factors to the effects of color segregation observed in Experiment 1.

EXPERIMENT 2

The stimulus displays formed a subset of those employed in Experiment 1 and comprised the displays with target alone or with purely compatible, mixed compatible-neutral, or purely neutral noise. Formally, the response rules were the same as in Experiment 1, but the exclusion of incompatible noise elements changed the nature of the task as follows. Any display required one or the other response according to whether the display contained one or more Ts or one or more Fs, regardless of spatial position. Subjects might therefore be expected to divide attention between the letters in a display rather than focusing attention on the target. If so, effects of color segregation dependent on variations in efficiency of attentional focusing should disappear. On the other hand, effects of color segregation due to nonattentional perceptual conditions such as color-based variations in segmentation time or color-specific inhibitory lateral interactions should still be evident. Thus, finding no improvement in performance with color segregation in this experiment would confirm a purely attentional interpretation of the effects demonstrated in Experiment 1.

Method

Subjects. Six of the eight subjects who served in Experiment 1 participated in Experiment 2. The two subjects who did not participate in Experiment 2 are those represented in Figure 2 by closed downward-pointing triangles (the subject with deviant results) and open circles (subject selected at random).

Stimuli. The stimulus material consisted of two main blocks of slides, Blocks A and B. The slides were copies of originals used in Experiment 1. In Block A slides, noise elements were absent or response compatible; in Block B, noise was mixed compatible-neutral or purely neutral.

Each main block contained five consecutive subblocks: one practice subblock and four experimental subblocks. The practice subblock contained 42 duplicates of slides forming a representative sample from the four experimental subblocks. In Block A, each experimental subblock contained two slides for warming up followed by a randomly ordered set of 40 test slides consisting of one copy of each of the 16 target-alone originals used in Experiment 1 and one copy of each of the 24 originals with purely compatible noise. Similarly, in each experimental subblock of Block B, two slides for warming up were followed by a randomly ordered set of 56 test slides consisting of one copy of each of the 32 originals with mixed compatible-neutral noise and one copy of each of the 24 originals with purely neutral noise.

Procedure. Apparatus, viewing conditions, and procedure were the same as in Experiment 1 with the following exceptions. The subjects served in two experimental sessions. Each session comprised a run through Blocks A and B with a pause of about 15 min between main blocks and a 1-min break between subblocks. Order of main blocks was counterbalanced over subjects and sessions. For each subject, the mapping of stimuli to responses was consistent with that required in the previous experiment.

Results

All reactions on the 4,608 test trials were faster than 2,000 msec. Reaction time analyses were based on correct reactions. Individual error rates ranged between .004 and .099, but individual data were similar in structure.

Reaction times for three-element displays were subjected to a three-factor repeated-measures ANOVA with four levels of the response compatibility factor (the four combinations of compatible and neutral left and right noise letters), four levels of the color segregation factor (segregation of none, left, right, or both noise letters), and two levels of target color (red vs. black). The effect of response compatibility was significant under the Greenhouse-Geisser procedure [$F(1,5) = 12.7$, $p < .05$]. The effects of color segregation and target color were not significant (in each case, $F < 1$), nor were any of the interactions (in each case, $p > .05$).

Table 2 shows mean reaction time and error rate as functions of response compatibility with and color segregation from target for left and right noise elements, averaged over target colors. Mean reaction times were 395, 410, 420, and 435 msec for color-nonsegregated displays with purely compatible noise, no noise, mixed compatible-neutral, and purely neutral noise, respectively, all pairwise differences being significant at a level of .05 by (nonorthogonal) t tests. The corresponding error rates showed a similar pattern.

Effects of color segregation were negligible. Averaged across the four combinations of compatible and neutral noise elements, mean reaction time was 418, 420, and 420 msec by color segregation of none, one, or both noise elements, respectively. Corresponding error rates were .044, .044, and .049. The contrasts in latency (t tests) and accuracy (chi-square) between reactions to displays with color segregation of none vs. both noise elements were not significant for any noise combination (in each case, $p > .05$).

Discussion

The effects of purely compatible noise differed from those observed in the previous experiment. In Experiment 1, reactions to displays with purely compatible noise were slower, though more accurate, than reactions to no-noise displays. This finding suggested that subjects were more cautious with three-element than with one-element displays, which seemed to be a reasonable strategy, since two-thirds of the noise elements were neutral or incompatible. The same stretegy would seem inappropriate in Block A of Experiment 2, in which all noise elements were compatible with the target. Thus, it is not surprising that, in Experiment 2, a redundancy gain appeared in both reaction times and error rates when the target was presented with compatible noise rather than alone.[4]

Since incompatible noise elements were excluded in Experiment 2, one or the other response was required depending on whether the display contained one or more Ts or one or more Fs, regardless of spatial position. Subjective reports confirmed the expectation that, in these conditions, subjects would divide attention between the elements in the display rather than focusing attention on the central target. Hence, if the improvement in performance with color segregation observed in Experiment 1 was caused by gain in the efficiency of focusing attention on the target, no improvement in performance with color segregation should be expected in Experiment 2. Moreover, there should be no basis for a speed-accuracy tradeoff like that invoked in analyzing the effects of color segregation for compatible and neutral noise in Experiment 1. The results fulfilled with these expectations.

Alternative interpretations of Experiment 1 might account for the data from that experiment by hy-

Table 2

Mean Reaction Time (in Milliseconds) and Error Rate (ER) as Functions of Response Compatibility With and Color Segregation From Target for Left and Right Noise Letters in Experiment 2

Compatibility of		Segregation of							
		None		Left		Right		Both	
Left	Right	RT	ER	RT	ER	RT	ER	RT	ER
				Block A					
Blank	Blank	410	.051						
Compatible	Compatible	395	.026	398	.063	398	.063	405	.042
				Block B					
Compatible	Neutral	423	.063	427	.047	424	.036	425	.068
Neutral	Compatible	418	.042	424	.052	436	.036	418	.047
Neutral	Neutral	435	.055	425	.026	429	.031	431	.047

Note–Data are group results for six subjects.

pothesizing nonattentional perceptual effects of color segregation such as variations in segmentation time or in strength of inhibitory lateral interactions. Experiment 2 was designed to evaluate such effects. By hypothesis, the perceptual effects should be the same whether attention is focused or divided. Thus, if color segregation of noise from target automatically speeded up the perceptual segmentation of a three-element display into separate units at the level of single characters, or automatically weakened inhibitory lateral interactions between noise and target, then perception and performance would be expected to improve by color segregation in Experiment 2. The results went counter to this expectation.

CONCLUDING REMARKS

The results of Experiment 2 confirmed our attentional interpretation of the effects of color segregation observed in Experiment 1. The interpretation implies that perceptual segregation by color improved the efficiency of focusing attention on the target to the exclusion of the noise. Thus, within the field of central foveal vision, spatial selectivity was enhanced by changing the perceptual organization without changing the spatial arrangement or the task-related informational value of the stimulus elements.

REFERENCES

Banks, W. P., & Prinzmetal, W. Configurational effects in visual information processing. *Perception & Psychophysics*, 1976, **19**, 361-367.

Bjork, E. L., & Murray, J. T. On the nature of input channels in visual processing. *Psychological Review*, 1977, **84**, 472-484.

Broadbent, D. E. Stimulus set and response set: Two kinds of selective attention. In D. I. Mostofsky (Ed.), *Attention: Contemporary theory and analysis*. New York: Appleton-Century-Crofts, 1970.

Cahill, M.-C., & Carter, R. C. Color code size for searching displays of different density. *Human Factors*, 1976, **18**, 273-280.

Carter, R. C. Visual search with color. *Journal of Experimental Psychology: Human Perception and Performance*, 1982, **8**, 127-136.

Clark, S. E. Retrieval of color information from preperceptual memory. *Journal of Experimental Psychology*, 1969, **82**, 263-266.

Colegate, R. L., Hoffman, J. E., & Eriksen, C. W. Selective encoding from multielement visual displays. *Perception & Psychophysics*, 1973, **14**, 217-224.

Egeth, H. Attention and preattention. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 11). New York: Academic Press, 1977.

Eriksen, B. A., & Eriksen, C. W. Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, 1974, **16**, 143-149.

Eriksen, C. W., & Eriksen, B. A. Target redundancy in visual search: Do repetitions of the target within the display impair processing? *Perception & Psychophysics*, 1979, **26**, 195-205.

Eriksen, C. W., Hamlin, R. M., & Daye, C. The effect of flanking letters and digits on speed of identifying a letter. *Bulletin of the Psychonomic Society*, 1973, **2**, 400-402.

Eriksen, C. W., & Hoffman, J. E. Temporal and spatial characteristics of selective encoding from visual displays. *Perception & Psychophysics*, 1972, **12**, 201-204.

Eriksen, C. W., & Hoffman, J. E. The extent of processing of noise elements during selective encoding from visual displays. *Perception & Psychophysics*, 1973, **14**, 155-160.

Eriksen, C. W., Morris, N., Yeh, Y.-Y., O'Hara, W., & Durst, R. T. Is recognition accuracy really impaired when the target is repeated in the display? *Perception & Psychophysics*, 1981, **30**, 375-385.

Eriksen, C. W., & Schultz, D. W. Information processing in visual search: A continuous flow conception and experimental results. *Perception & Psychophysics*, 1979, **25**, 249-263.

Farmer, E. W., & Taylor, R. M. Visual search through color displays: Effects of target-background similarity and background uniformity. *Perception & Psychophysics*, 1980, **27**, 267-272.

Flom, M. C., Weymouth, F. W., & Kahneman, D. Visual resolution and contour interaction. *Journal of the Optical Society of America*, 1963, **53**, 1026-1032.

Francolini, C. M., & Egeth, H. E. Perceptual selectivity is task dependent: The pop-out effect poops out. *Perception & Psychophysics*, 1979, **25**, 99-110.

Francolini, C. M., & Egeth, H. E. On the nonautomaticity of "automatic" activation: Evidence of selective seeing. *Perception & Psychophysics*, 1980, **27**, 331-342.

Fryklund, I. Effects of cued-set spatial arrangement and target-background similarity in the partial-report paradigm. *Perception & Psychophysics*, 1975, **17**, 375-386.

Green, B. F., & Anderson, L. K. Color coding in a visual search task. *Journal of Experimental Psychology*, 1956, **51**, 19-24.

Hellige, J. B. Effects of perceptual quality and visual field of probe stimulus presentation on memory search for letters. *Journal of Experimental Psychology: Human Perception and Performance*, 1980, **6**, 639-651.

Hellige, J. B., & Webster, R. Right hemisphere superiority for initial stages of letter processing. *Neuropsychologia*, 1979, **17**, 653-660.

Humphreys, G. W. Flexibility of attention between stimulus dimensions. *Perception & Psychophysics*, 1981, **30**, 291-302.

Kahneman, D. *Attention and effort*. Englewood Cliffs, N.J: Prentice-Hall, 1973.

Kahneman, D., & Henik, A. Effects of visual grouping on immediate recall and selective attention. In S. Dornic (Ed.), *Attention and performance VI*. Hillsdale, N.J: Erlbaum, 1977.

Kahneman, D., & Henik, A. Perceptual organization and attention. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization*. Hillsdale, N.J: Erlbaum, 1981.

Keren, G. Some considerations of two alleged kinds of selective attention. *Journal of Experimental Psychology: General*, 1976, **105**, 349-374.

Krueger, L. E., & Shapiro, R. G. Repeating the target neither speeds nor slows its detection: Evidence for independent channels in letter processing. *Perception & Psychophysics*, 1980, **28**, 68-76.

Neisser, U. *Cognitive psychology*. New York: Appleton-Century-Crofts, 1967.

Polich, J. M. Hemispheric differences in stimulus identification. *Perception & Psychophysics*, 1978, **24**, 49-57.

Prinzmetal, W., & Banks, W. P. Good continuation affects visual detection. *Perception & Psychophysics*, 1977, **21**, 389-395.

Santee, J. L., & Egeth, H. E. Interference in letter identification: A test of feature-specific inhibition. *Perception & Psychophysics*, 1980, **27**, 321-330.

Santee, J. L., & Egeth, H. E. Independence versus interference in the perceptual processing of letters. *Perception & Psychophysics*, 1982, 31, 101-116.

Shiffrin, R. M., & Schneider, W. Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review*, 1977, **84**, 127-190.

Smith, S. L. Color coding and visual search. *Journal of Experimental Psychology*, 1962, **64**, 434-440.

Taylor, D. A. Time course of context effects. *Journal of Experimental Psychology: General*, 1977, **106**, 404-426.

Treisman, A. M., & Gelade, G. A feature-integration theory of attention. *Cognitive Psychology*, 1980, **12**, 97-136.

Ullmann, J. R. *Pattern recognition techniques*. London: Butterworth, 1973.

Wertheimer, M. Untersuchungen zur Lehre von der Gestalt II. *Psychologische Forschung*, 1923, **4**, 301-350.

Williams, L. G. The effect of target specification on objects fixated during visual search. *Perception & Psychophysics*, 1966, **1**, 315-318.

Winer, B. J. *Statistical principles in experimental design* (2nd ed.). New York: McGraw-Hill, 1971.

Wolford, G. Perturbation model for letter identification. *Psychological Review*, 1975, **82**, 184-199.

Wolford, G., & Hollingsworth, S. Lateral masking in visual information processing. *Perception & Psychophysics*, 1974, **16**, 315-320.

von Wright, J. M. Selection in visual immediate memory. *Quarterly Journal of Experimental Psychology*, 1968, **20**, 62-68.

von Wright, J. M. On selection in visual immediate memory. *Acta Psychologica*, 1970, **33**, 280-292.

von Wright, J. M. On the problem of selection in iconic memory. *Scandinavian Journal of Psychology*, 1972, **13**, 159-171.

NOTES

1. It may be questioned whether decrease in error rate is an adequate measure of "gain in accuracy." Should a change in error rate from .04 to .02 really be considered a greater gain in accuracy than, say, a change from .02 to .005? The problem may be circumvented by making a less powerful, nonparametric test for interaction between response compatibility and color segregation in accuracy, a test based on the signs rather than the numerical values of differences in error rate. For the nine combinations of noise letters in order of increasing mean reaction time (across conditions of color segregation), the signs of the differences in error rate produced by two-sided color segregation were +, +, +, +, −, +, −, −, and −, respectively. A total of 2 of $\binom{9}{5} = 126$ possible sequences of five +s and four −s are equally, or more, favorable to the hypothesis that the greater the mean reaction time for a combination of noise letters, the greater the probability of observing a decrease rather than an increase in error rate by two-sided color segregation ($p < .05$).

2. Chi-square was computed by subjecting individual data to Fisher exact probability tests, converting one-tailed probabilities to values of chi-square for two degrees of freedom, and summing over subjects (cf. Winer, 1971, p. 49).

3. As lateral masking should be stronger in the direction from the periphery toward the center than in the opposite direction (cf. Wolford & Hollingsworth, 1974), improvement in sensory information obtained by color segregation might be greater for the target than for the color-segregated noise. Such asymmetry would enhance the gain in performance effected by color segregation.

4. The results of Experiment 2 argue against the notion of color-specific inhibitory lateral interactions between display elements, but the data are consistent with the hypothesis that color-nonspecific inhibitory lateral interactions occurred between the elements. Thus, it is possible that three factors underlay the difference in performance for displays with purely compatible noise vs. no-noise displays in Experiment 1: (1) facilitation from compatible elements grounded in the fact that sensory information was noisy with respect to spatial position; (2) lateral masking; and (3) speed-accuracy tradeoff such that subjects were more cautious with three-element than with one-element displays. In Experiment 2, reactions were presumably based on detection of a T or detection of an F without regard to spatial position. Facilitation by target redundancy would then be expected to be stronger than in Experiment 1, whereas strength of lateral masking should be the same. The clear gain in performance for displays with purely compatible noise as compared with displays without noise indicates that, in these conditions, gain by facilitation was greater than loss by masking. For related results and discussion, see Bjork and Murray (1977), C. W. Eriksen and B. A. Eriksen (1979), C. W. Eriksen, Morris, Yeh, O'Hara, and Durst (1981), Krueger and Shapiro (1980), and Santee and Egeth (1980, 1982).

(Manuscript received June 8, 1982;
revision accepted for publication September 24, 1982.)